The other question: what should be done with the manuscripts remains an open problem. The plotted *charts* are not accurate enough for photographic reproduction, nor will they ever be used for engraving, since charts can be engraved directly from the catalogues with greater accuracy. The *catalogues*, on the other hand, could be published at less expense, and would afford a welcome comparison with other work of the same kind, or with the ecliptic charts of Chacornac, Peters, and Palisa.

Since the readers of this note are probably aware of the forthcoming *Atlas Stellarum Variabilium*, it may be of interest to them to know that its plan was laid out previous to any knowledge of Pogson's work, and that its observations were practically finished before his manuscripts were examined. It seemed to be preferable to make no use of Pogson's catalogues in preparing this Atlas and to leave a comparison of the two works to a future time when his results will be more generally accessible.

Georgetown College Observatory:
1898 *October* 10.

On a New Instrument for measuring Astrophotographic Plates. By David Gill, C.B., F.R.S., &c., Her Majesty's Astronomer at the Cape of Good Hope.

Introductory.

The apparatus formerly employed at the Cape for measuring "Catalogue plates" resembled in general construction the one originally made by Messrs. Repsold of Hamburg for Professor Bakhuyzen, and which is described by him (*Bulletin du Comité Permanent*, tome i. pp. 169–173).

In lieu of the original microscope by which a single coordinate of the image of a star on the plate could be projected on and measured by a scale divided on metal, Messrs. Repsold made for me a very perfect micrometer having two screws at right angles to each other, by which both coordinates of a star could be measured relative to the sides of the including réseau.

With this apparatus the coordinates of about 8,000 stars were measured. The method of observation was to point on one réseau-line, then on the edges of the star-disc, then twice on the centre of the star-disc, then on the opposite réseau-line, and finally to repeat the operation in the reverse order.

Thus the measurement of each coordinate, and of the star's diameter, involved sixteen pointings and sixteen readings of the microscope. The process was unquestionably very accurate, but it cost far too much time in observing and in reduction to offer any hope of completing the programme of observation in a reasonable time—at least with the means placed at my disposal.

Having examined Professor Turner's now well-known method, by which the coordinates of the star's image are referred to glass scales placed in the common focus of the eyepiece and object-glass of the microscope, I could not satisfy myself that results of adequate accuracy could be secured by such means. Trial of the apparatus convinced me that the observer could not be at all certain of estimating the tenth part of the 3″ intervals into which the scales are ruled, especially as division on glass with a diamond does not yield very clean and sharp fine lines; and, even supposing that the observer could exactly estimate the $\frac{1}{10}$th part of such 3″ intervals, his smallest estimated measure is 0″·3, which is extravagantly large, seeing that, on a fairly good plate, a star's image can be pointed upon with a filar micrometer with a probable error rather under than over ±0″·1. Indeed, with such a method of observation the calculation of true probable error is impossible, because, unless the definition of the microscope is very bad, or the image of the star is bad, or the scales are defective in precision of division, the observer should always observe to the same $\frac{1}{10}$th of a division. This criticism does not apply quite strictly to Professor Turner's last computations of the probable error of the Oxford measures, where the plate is reversed 180° without reversing the micrometer scale, because in this case the réseau-lines intersect the scales at different points from those of the previous measurement. But no confidence can be placed in estimates of probable error by this method of observation when, as at Greenwich, the scales are reversed with the plate, and the réseau-lines are referred to the same points of the scales in the two positions of the plate.

Recognising the necessity for more rapid means of working, I endeavoured to devise an instrument which, retaining the rapidity of Professor Turner's method, should also retain the accuracy which is attainable with the filar micrometer. The result has fully realised my expectations, thanks to the artistic skill and care of Messrs. Repsold, to whom I entrusted the carrying out of my plans.

The Essential Features of the New Instrument.

The essential conditions of construction are :—

1. The micrometer to be webbed with a "fixed square," 5 mm. × 5 mm., the sides of this square being parallel spider-webs 4″ (of arc) apart. The size of the square is reckoned from centre to centre of these double webs.
2. The object-glass of this micrometer to be placed midway between the plane of the photographic plate and the plane of the webs.
3. The two micrometer screws at right angles to each other which actuate the movable slides to have heads divided into 100 parts, one revolution = 0·5 mm.; so that ten revolutions are = 5 mm., or = the interval between two

adjacent réseau-lines, or=the interval between the sides of the fixed square of webs.

4. Two other screws, the heads of which are not graduated, to give motions to the whole micrometer-box through ± 1 mm. in directions parallel to the axes of the two micrometer screws.
5. Each micrometer screw to move a system of six parallel wires placed 4″ (of arc) apart from each other. These wires to serve, not only for pointing on stars to determine their coordinates (in manner afterwards described), but also for estimating their diameters in terms of these 4″ intervals.
6. All the essential parts of the micrometer, including the slides, micrometer-box, tube, &c., to be of steel or cast iron, so that changes of temperature shall not affect the adjustments.

The necessary adjustments are the following :—

a. The webs of each set of movable wires shall, *inter se*, be strictly parallel, and the two sets shall be strictly at right angles to each other.

b. The double webs composing the sides of the fixed square shall be strictly parallel, and shall form a true square of exactly ten revolutions of the screw on the side.

c. The two micrometer screws shall be without sensible periodic or other error, and exactly alike in pitch.

d. The image of a normal réseau-square, as viewed in the microscope, shall exactly coincide with the square formed by the fixed webs; that is to say, the image of the sides of a normal réseau-square shall measure exactly 10 screw revolutions.

e. The micrometer readings for coincidence of the movable webs with the webs of the fixed square shall be exactly $0^{R}\cdot 000$ and $10^{R}\cdot 000$.

Assuming for the moment that these conditions are rigidly realised, we have the following very simple *modus operandi* :—

α. By means of the quick rack-motion move the plate so as to bring the réseau-square into the centre of the field of the micrometer; then, by means of the micrometer screws with undivided heads, perfect the coincidence of the fixed wires with the image of the réseau-square, as in the figure on page 64.

β. By means of one of the micrometer screws, X, point the movable set of six wires on the image of the star-disc.

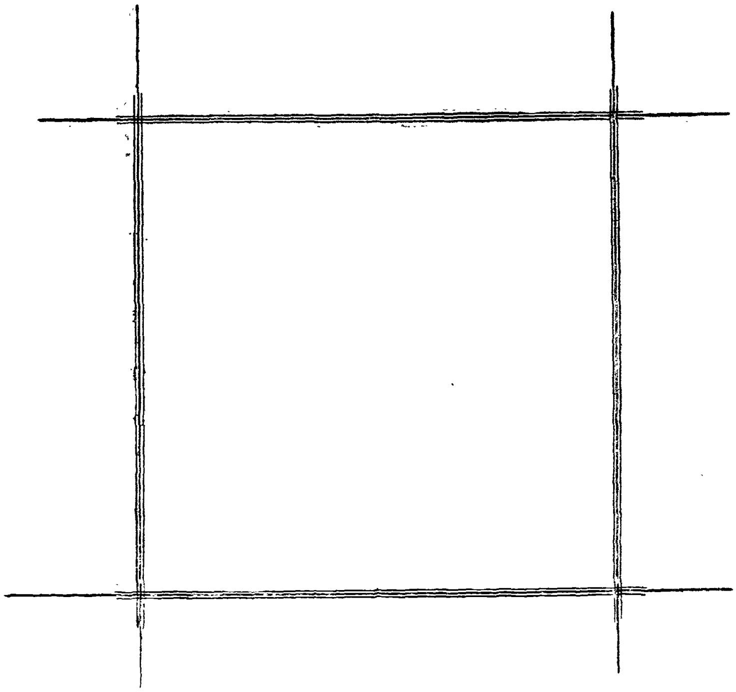
γ. Similarly bisect the star-image with the screw Y.

δ. Estimate the diameter of the image in terms of the 4″ intervals of the movable webs.

The reading of the pointing β is then the required coordinate in x, and that of γ the required coordinate in y; or, if the plate

is reversed 180°, the readings have to be subtracted from $10^{R}\cdot000$.

The whole process is so simple that an observer without any previous knowledge or experience in practical work of the kind can, after very short training, easily measure the two coordinates of eighty stars per hour (including diameters); and, were it not that the observers are instructed to work very carefully, a larger number could be measured in the same time.



Coincidence of fixed wires with image of réseau-square.

It remains to be described how the necessary adjustments are made, how preserved constant, what effect possible residual errors in these adjustments may have in the resulting coordinates, and what accuracy experience has shown can be attained in the resulting coordinates.

Adjustment *a*.—The six parallel webs, 4″ apart, which are moved by each of the measuring screws, have no adjustment for parallelism with each other, but the web-furrows have been ruled with an exquisitely fine and sharp cutter in a ruling machine of such perfection that no error in their parallelism can be detected even when the webs are successively placed in all but apparent contact with one of the fixed webs under an eyepiece of $\frac{1}{5}$-inch focal length, specially used for this purpose and for determining coincidence.

For adjustment of the two sets of six webs at right angles to each other, the ruling of the web-furrows at one side of one of the movable frames has been made, not on the upper surface of the frame itself, but on a small supplementary slide attached to

the main frame. This supplementary slide is adjustable by two fine opposing screws, the heads of which can be turned by a long screw-driver of small diameter, which may be inserted through suitable holes in the sides of the micrometer box. When the adjustment is completed these holes are closed by small metal plugs to exclude dust. The adjustment can be made by placing an original réseau, the lines on which are known to be perfectly at right angles to each other, under the micrometer, and making the two sets of movable webs to coincide with the image of the réseau-lines. No trace of change in the accuracy of this adjustment can be detected.

Adjustment *b*.—The parallelism to each other of the double webs, 4″ apart, which constitute the four sides of the fixed square has been secured once for all by the perfection of the ruling of the web-furrows. It remains—

(1) To adjust two sides of the square parallel to their corresponding movable webs.
(2) To adjust the two opposite sides, not only also parallel to the movable webs, but also exactly 10·000 revolutions of the screw distant from the other two sides.

For this purpose the web-furrows at one extremity of one of the sides of the square are ruled, not on the central fixed frame itself, but on a small supplementary plate, which has slight adjustment by means of a screw and opposing spring. The web-furrows on the opposite sides of the fixed frame are ruled, not in the frame, but on two plates provided with similar adjustments. Access to the heads of these screws is attained in the same way as in adjustment *a*. With a little care and patience it is thus comparatively easy to make the sides of the square strictly parallel to the movable webs, and each side of the square to measure exactly 10·000 revolutions—at least within $0^{R}\cdot001$ or $0^{R}\cdot002$.

Adjustment *c*.—This demands perfect equality and perfection in truth of the two screws, and is necessarily left to the artist. Messrs. Repsold have apparently attained practical perfection by careful final grinding of both screws in the same matrix. The screws are practically identical, and can even be interchanged in the micrometer without affecting the apparent measured lengths of the sides of the fixed square.

Adjustment *d*.—The microscope is provided with two focussing adjustments, both of which are regulated by screws with divided heads acting against opposing springs.

(1) moves the object glass (which is mounted on an inner tube sliding in the outer tube), nearer to or farther from the plate.
(2) moves the micrometer box nearer to or farther from the object glass—in other words, changes the total length of the fixed tube.

By means of these two screws it is very easy to adjust the micrometer so that the images of the sides of réseau-square fit symmetrically between the parallel webs of the fixed square. This adjustment once made is not liable to change, but on account of shrinkage of the film and division error of the réseau, it is never found that all the images of the réseau-squares of any plate exactly fit the fixed square.

The fact that the object glass is placed midway between the conjugate foci offers the great advantage that, by a small movement of the object-glass, the size of the image of the réseau-square can be changed relative to the size of the "fixed square" of the micrometer without disturbing the sharpness of the images. Thus, for the measurement of each separate coordinate it becomes possible to adjust the image of the including sides of the réseau-square to exact coincidence with the corresponding sides of the fixed square by simple movement of the screw (1).

As a matter of experience, however, the following plan is found to be more satisfactory, viz. to measure a number of squares on the plate, find the mean value, and, if that is not perfectly $=10^{\mathrm{R}}\cdot000$, apply the necessary correction to the run by moving the graduated head of screw (1) through the required amount. When the image of any particular square (on account of division error in the original réseau or of shrinkage of the film) does not exactly fit the fixed square, then make a symmetrical pointing.

In this way we automatically make the reading $5^{\mathrm{R}}\cdot000$ to correspond with the true middle point between the sides of the réseau-square, and practically we measure the distance of the star from this middle point in terms of true mean revolutions.

Adjustment *e*.—The rounded end of each micrometer screw is pressed against the flat end of an adjusting screw (which is tapped into the side of the micrometer box) by the counter spring of the micrometer slide. It is obvious that, by this screw, it is very easy to adjust the reading of the screw-head to zero for coincidence readings of the movable with the fixed wires.

Results of Experience with the New Instrument.

It may appear to the reader that a micrometer of this kind is a complex instrument liable to derangement in its adjustments either by unskilful handling or by change of temperature.

It is true that the design of the interior of the micrometer box is of necessity somewhat complex; but experience has shown remarkable constancy in the adjustments and extreme ease and simplicity in working. This result is due to the solidity and perfection of the design and workmanship, and to the similarity of the temperature coefficients of expansion of all the principal parts. As a matter of fact, since I made the final adjustments, I have only once had occasion to change them, and that was when one of the webs was accidentally broken and I had to dismount the micrometer to replace it.

Coincidence of the movable webs with the corresponding sides of the fixed square is determined for each screw at 0^R and 10^R, generally before the measurement of each plate; the results agree within $\pm 0^R{\cdot}002 = (\pm 0''{\cdot}06)$. But even if these errors were much larger they would have very little influence on the result of two pointings on reversed positions of the plate.

Every plate is measured twice—once in one position, once in a position reversed 180° with respect to the microscope. Two observers, sometimes three, take part in the measurement of each plate. One observer measures the coordinates of all the stars on the first 5′ zone, the other acting as clerk. The observers exchange work in the next 5′ zone, and so on till the plate is finished. When the plate is reversed each observer re-measures the same 5′ zones as he or she previously measured in the former position. Before any plate is measured the images of the reference stars on the plate (ten to twelve in number, the places of which have been specially observed on the meridian) are marked by circles in ink drawn on the reverse side of the plate, and these ten to twelve images are measured by all the observers who cooperate in the measurement of that plate.

The process above described has the following advantages:—

1. All personality depending on right and left directions of measurement, and hence on magnitude, is eliminated.
2. All index error, depending on the reading for coincidence of the movable with the fixed wires, is completely eliminated.
3. The outstanding error of run over ten revolutions is always very small, because, if after measuring a number of réseau-squares with the screw it is found that the mean is not exactly $10^R{\cdot}000$, the necessary correction is at once applied by moving the object glass nearer to or farther from the plate, the necessary amount of correction being known by the graduations on the head of the focussing screw. It would therefore be a very extreme error to adopt $\pm 0''{\cdot}1$ as the possible amount of outstanding error of run over ten revolutions.

If the fixed square is pointed symmetrically on the réseau-square, the reading "$5^R{\cdot}000 \pm$ index-error" must correspond to the true middle point between the réseau-lines (the sign of the index error being + in one position of the plate and − in the other position). Therefore, if a star is at or near $5^R{\cdot}0$, its coordinate will be determined free from error of run. If the star is situated near one side of the square, the coordinate would be affected by half the error of run over ten revolutions, *i.e.* in an extreme case by $\pm 0''{\cdot}05$. In all intermediate positions the effect of an error of run of $0''{\cdot}1$ in ten revolutions will lie between $0''{\cdot}00$ and $0''{\cdot}05$.

To derive an approximate idea of the accuracy of the method,

we may discuss the difference between the direct and reverse measures of coordinates actually obtained in practice.

This difference "direct *minus* reverse" arises from the following causes:—

(1) Accidental error of pointing the "fixed square" on the réseau-square.
(2) Accidental error of pointing the movable wires on the star's image.
(3) Twice the personal equation depending on magnitude, or on right and left directions of measurement.
(4) Twice the outstanding error of the zero adjustment for coincidence.
(5) A part (never greater than one-half) of the error of adjustment for run over ten revolutions.

Except near the corners of the plate, it very seldom happens that the difference between the readings direct and reverse amounts to $0^{R}\cdot02 = 0''\cdot6$. Whenever such a difference occurs (perhaps once in 50 or 100 stars) the readings in both positions of the plate are repeated.

At Greenwich and Oxford the rule seems to be to repeat the measures only when discordance "reverse minus direct" amounts to $1''\cdot5$!

To compute the probable error of observation, I have taken the plate No. 9722, zone $-41°$, $\alpha_0 = 18^h\ 35^m$, in the measurement of which three observers took part, *viz.* Misses Bowman, Stephens, and Halkett.

The plate contains 702 measured stars, ten of which occur on the list of standard stars. The zones were equally divided amongst the three observers, each measuring her special zones in both reversed positions of the plate.

From the differences "direct minus reverse," without any corrections for constant differences, we find:—

	B	S	H
	R	R	R
"Direct – reverse" mean	+0·0001	+0·0015	+0·0035
Mean of the squares of the differences "Direct – reverse"	0·000076	0·000081	0·000073
$\sqrt{\text{of the above}}$ (in arc)	$\pm 0''\cdot261$	$\pm 0''\cdot270$	$\pm 0''\cdot255$

Whence we have

The probable error of 1 observation .	$\pm 0''\cdot123$	$\pm 0''\cdot127$	$\pm 0''\cdot121$
And the probable error of each coordinate resulting from the two observations in reversed positions of the plate	$\pm 0''\cdot088$	$\pm 0''\cdot090$	$\pm 0''\cdot085$

Of the original observations of the 702 stars eight had to be repeated for discordance between the readings in the two positions exceeding $\pm 0^{R}\cdot02$ ($= \pm 0''\cdot60$).

These probable errors are perhaps slightly in excess of the true probable errors, because they include twice the coincidence error and perhaps a small error depending on run.

The better to determine how far this is the case, I give the results of the measures of the standard stars by each of the three observers.

Standard Star.	x B	x S	x H	y B	y S	y H
	R	R	R	R	R	R
(1)	8·795	8·802	8·803	7·636	7·637	7·644
(2)	9·248	9·240	9·245	0·040	0·033	0·036
(3)	8·043	8·050	8·043	5·182	5·178	5·178
(4)	2·266	2·264	2·262	0·231	0·225	0·220
(5)	9·040	9·039	9·040	4·336	4·337	4·329
(6)	2·536	2·528	2·534	1·628	1·626	1·625
(7)	0·697	0·692	0·690	3·617	3·618	3·618
(8)	8·212	8·216	8·205	8·698	8·703	8·707
(9)	2·256	2·260	2·266	5·140	5·134	5·138
(10)	5·616	5·604	5·615	4·815	4·820	4·813

If now we take the means for each coordinate of each star, and subtract these means from the corresponding coordinate obtained by each observer, and take the mean of the squares of the residuals thus formed, we get for the different observers :—

	B	S	H
Mean of the square of the residuals	0·0000115	0·0000092	0·0000134

These mean squares are = $\frac{2}{3}$ of the square of the mean error, because for each of the three residuals from each star there is one unknown quantity.

Thus :

	B	S	H
The mean error of a coordinate as derived by each observer is	R ±0·00415	R ±0·00371	R ±0·00448
And the corresponding probable errors in arc are	±0″·082	±0″·074	±0″·089

Description of Details of Construction.

The instrument, as shown in Plate 2, is built upon a circular cast-iron base-plate, which in use rests on a stand of walnut wood inclined at an angle of 45°.

The micrometer-holder is attached to a strong cast-iron tribrach, which is supported from the base-plate by three iron pillars.

Provision for motion of the plate in one direction is made by a strong cast-iron slide with two pairs of segmental bearings, which rest on the steel cylinder *a b* and on a single bearing on a

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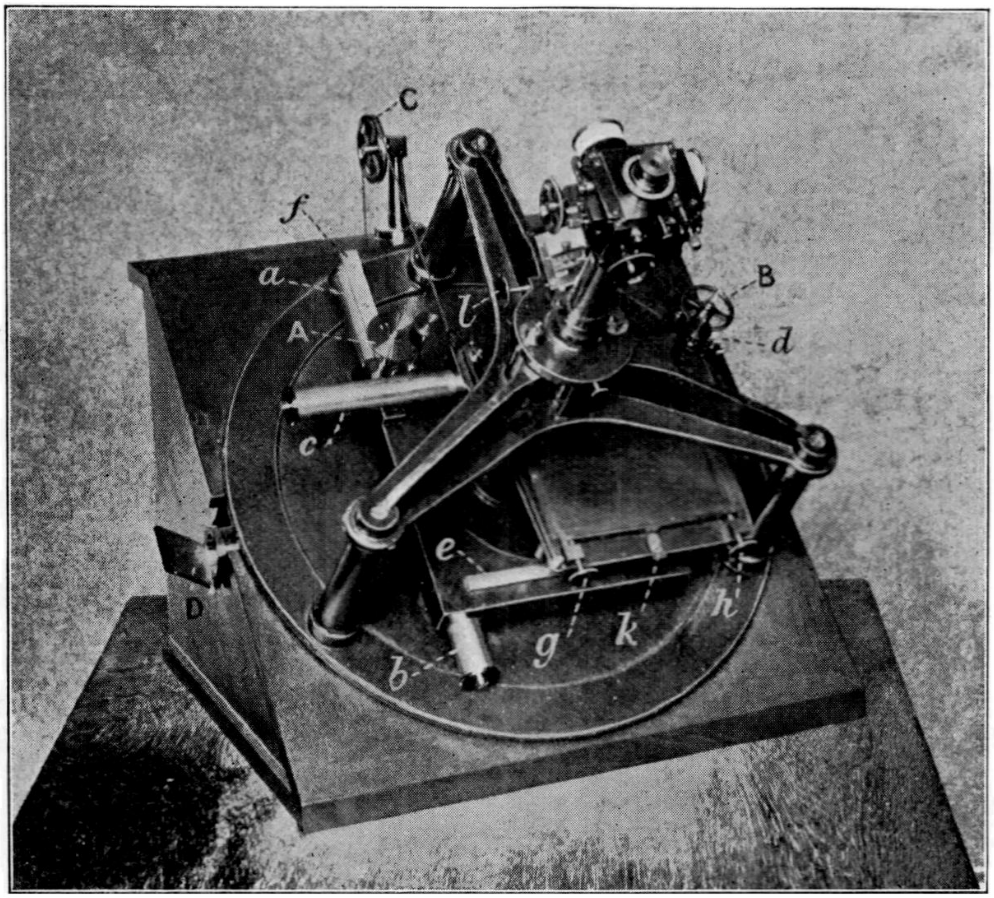
true plane formed on the base-plate. Motion at right angles to the former direction is given by a second slide, mounted similarly to the first slide upon the cylinder *c d*, and on a true plane *e* formed on the first slide.

To each cylinder is attached a bar of German silver, *f*, one side of which is toothed; the other side is graduated at each fifth millimetre. The handle A is connected with a pinion which works in the toothed side of the bar *f*, and gives quick motion to the plate in the direction of the axis of the cylinder *a b*. The smaller handle beside A clamps the slide to the cylinder *a b* when desired. The handle B similarly gives quick motion to the plate along the direction of the axis of the cylinder *c d*, and the smaller handle clamps the slide to the cylinder.

Each German silver scale has a double set of figures engraved upon it: one set, coloured black, corresponds with the réseau-readings in the "direct measures"; the other set, coloured red, corresponds with the réseau-readings in the "reverse measures."

Indices, which are adjustable to exact coincidence with the réseau-readings under the microscope, enable the observer to identify at sight the réseau-square under measurement. The two slides, being of considerable weight, are balanced by a counter-weight which is attached to a cord passing over the pulley C, so that the quick motion imparted to the slides by the handle A is equally easy in both directions.

The photographic plate is mounted on the upper slide, being pressed by springs, acting on its under surface, against three projecting stops which define the plane of the film. These stops and the planes of motion of the slide have been so carefully adjusted, once for all, that the film-surface of the plate is, and moves, perfectly at right angles to the axis of the microscope, and at a constant distance from its object-glass. The plate is also pressed by a spring, acting on the centre of its upper edge, against two stops, which can be moved by the screws *g* and *h*. These stops are simple projections on the ends of a strong spring which is fixed to the upper slide at *k*. The screws *g* and *h*, by bending this spring, permit the plate to be very easily adjusted, so that the réseau-lines are parallel to the axis of the cylinder *c d*. The projections at *g* and *h* touch the plate opposite the two extreme vertical réseau-lines. When the plate is moved to the extremity of its range on the cylinder *c d* (*i.e.* to the position shown in Plate 2), the extreme left-hand réseau-line is seen near the centre of the field of view of the microscope. To adjust the plate it is then only necessary to point a pair of the movable wires, or one side of the fixed square, on one of the horizontal réseau-lines near its left-hand extremity; then, by the handle B, move the plate to its full extent of range to the left: this brings the extreme right-hand réseau-line near to the centre of the micrometer field. If the same horizontal réseau-line still remains bisected, the adjustment is complete; if not, by means of the screw *h*, move the plate till the pointing is perfect; the adjust-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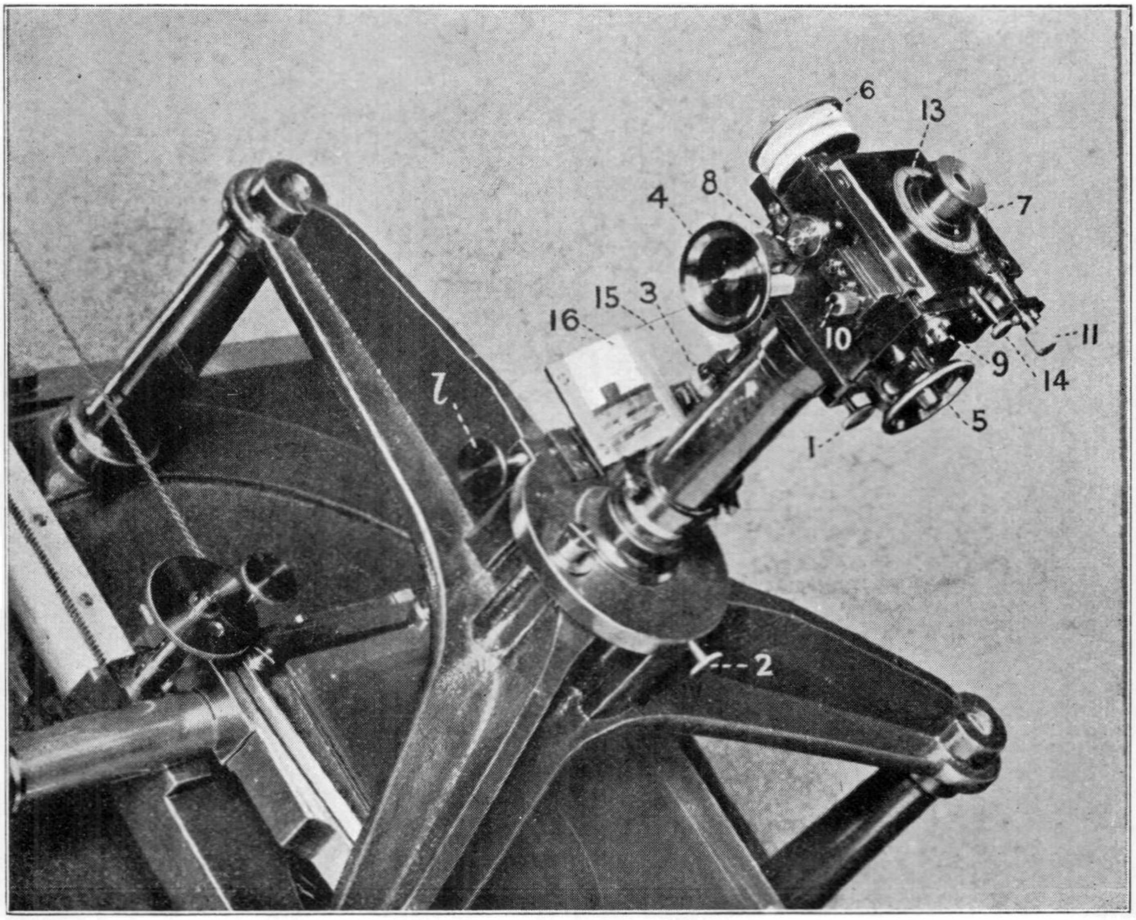
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ment is then perfected, so that the réseau-line remains bisected whilst the plate is traversed along the whole range of the cylinder *c d*.

The adjustment of the fixed square to parallelism with the réseau-lines is effected by two opposing screws, one of which is shown at *l*. By means of these screws the supporting tube of the micrometer may be delicately rotated in its bearing. This supporting tube, of cast iron, terminates in a broad flange and hollow pivot, and the latter fits smoothly in a hole in the tribrach.

The flange is held down by two screws with spring collars; the holes in the flange, by which these screws pass to the tribrach, being somewhat elongated, permit some rotation of the supporting tube of the microscope.

The screw *l* and its opposing screw pass through short arms (better seen on Plate 3), which are cast on the flange of the microscope-holder and press against a block on the tribrach. By these means the adjustment of the micrometer webs to parallelism with the réseau-lines can be made with the greatest certainty; and, once made, the adjustment of the orientation of the webs remains perfectly constant, although, of course, it is verified before the measurement of every plate.

For illumination of the field of the microscope Messrs. Repsold have introduced a great improvement. The observer sits with his back to the window of the measuring room, and light from the window is reflected from a mirror, D, made of silvered ground glass, and thence to a mirror at the back of the base-plate, the centre of which mirror is in the axis of the microscope, and inclined to it at an angle of 45°. From the latter mirror the light passes through a lens, which is fixed in the centre of the base-plate, and thence to the photographic plate. This illumination is remarkably uniform over the field and very suitable for accurate work, whilst the observers' eyes are shaded from the direct light of the window. It is indeed a substantial practical benefit, and the observers do not complain of the strain on the eyes as they did when they worked facing the light.

The details of the micrometer microscope are better seen in Plate 3.

The whole of the micrometer work is mounted on a steel tube which has been turned truly cylindrical, and slides very smoothly in bearings inside the cast-iron supporting tube, in which it can be firmly clamped by the screws 1 and 2.

The mounting of the object-glass slides inside this steel tube, its position inside the steel tube being adjusted and defined by the screw whose divided head is shown at 3. The screw which moves the steel tube inside the iron supporting tube is hidden in the plate by the micrometer-box.

The micrometer-box is double. The lower half contains the slides for movement of the upper box with respect to the tube by means of the undivided heads 4 and 5. The upper box contains

the square of fixed webs with their adjustments, and the slides, which are moved by the screws with graduated heads 6 and 7.

8 and 9 are the screws the ends of which form the end bearings of the micrometer screws, and by which the readings for coincidence of the movable webs with the fixed wires are reduced to zero.

10 and 11 move slides which enable the eyepiece to be centred over any part of the field. In ordinary work the lowest power eyepiece (shown in the plates) is used, with its axis in coincidence with that of the microscope tube, and having the whole fixed square within its range of sharp vision. In adjustment of the reading for coincidence and determination of run a much higher power is employed, and it is then only that the screws 10 and 11 are used.

13 is a small graduated circle attached to a hollow block which screws into the eyepiece slide. The eyepiece screws home into this hollow block; the readings of the graduated circle enable the observer to set his eyepiece-adjustment to the mean of several measures for focus of the eyepiece on the webs or on the image of the plate. When the focus of the eyepiece has been adjusted it can be clamped at the required reading by means of the screw 14.

The indices of the micrometer screw-heads are placed at the back, so that the screw-heads are read by reflection from the mirrors 15 and 16. These mirrors have adjustments which permit the micrometer readings to be made either by the microscope observer or by the clerk. Some observers prefer one method, some the other.

The graduations and figures of the micrometer-heads are engraved on celluloid; the jet black divisions and figures on the dull white surface are read with great ease and precision.

The instrument is equally perfect optically and mechanically, and has in every way more than realised my expectations. I gratefully acknowledge the skill and care, both in workmanship and design, with which Messrs. Repsold have carried out my general plans.